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Review

Collected marine litter – A growing waste challenge

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Abstract.

Marine litter, in particular plastic debris, poses a serious threat to marine life, human health and the economy. In order to reduce its impact, marine litter collections such as beach clean-ups are frequently conducted. This paper presents a systematic review of temporal developments, geographical distribution, quantities and waste treatment pathways of collected marine litter. Results from over 130 studies and projects highlight the world-wide increase in collection efforts. Many of these are in wealthy countries that do not primarily contribute to the problem. Over 250 thousand tonnes, have already been removed, but there is little or no information available regarding how this waste is treated or used post collection. This paper highlights the need for a whole-system quantitative assessment for the collection and waste treatment of marine litter, and identifies the challenges associated with utilising this waste in the future.

Keywords marine litter; life-cycle; systems perspective; collection; waste treatment

1. Introduction

Possibly the biggest landfill of our planet is the ocean. It accumulates various types of waste, called marine litter. This includes metals, glass, ceramics, textiles, paper and timber. Yet, the largest and probably most harmful fraction of marine litter is plastic debris. It is estimated that every year between 4.8 and 12.7 million tonnes of plastic waste enter the ocean from land-based sources alone (Jambeck et al., 2015). The high input is linked to plastics durability and lightweight which allows it unlike other types of marine litter to be easily transported via wind, waste water and rivers when it has been littered or inadequately disposed (Li, Tse and Fok, 2016). This is not only true for macroplastics but also for microplastics from e.g. car tire wear, clothes washing (Browne et al., 2011) and cosmetic products (Napper et al., 2015; Sherrington et al., 2016). Marine litter also originates from sea-based activities for example when fishing gear or cargo is lost, abandoned or discarded despite international legislation that prohibits the dumping of waste at sea (MARPOL Annex V, 1988; Jones, 1995).

Inside the ocean, marine litter is found in all seven ocean compartments: biota, coastlines, at the sea surface and the seafloor as well as in sediments, sea ice and the water column (Law, 2017; Figure 1). The contact with biota has been reported in 44 thousand reported cases of entanglement and ingestion affecting up to 1400 marine species worldwide (Gall and Thompson, 2015; Tekman et al., 2017a). Marine litter can also lead to a decline in tourism when washed ashore on beaches (McIlgorm, Campbell and Rule 2011; Keswani et al., 2016), destroy corals at the seafloor (Kühn, Bravo Rebolledo and van Franeker, 2015), spread invasive species (Kiessling, Gutow and Thiel, 2015) and cause accidents with ships (Cho, 2005). The plastic fraction of marine litter can be particularly harmful because it is able to travel over long time and distances before breaking down into smaller fragments (Andrady, 2011). Microplastics can then adsorb and release chemicals (Li, Tse and Fok, 2016), which become bioavailable after ingestion. This is also a risk for humans because these substances can accumulate along the biological food chain (Li, Tse and Fok, 2016).

On a political level, the United Nations Development Goals demand that the majority of countries worldwide “prevent and significantly reduce marine pollution” by 2025 (UN General Assembly, 2015). This may be achieved by implementing the increasingly popular framework of a closed-loop and resource efficient Circular Economy, as alternative to the established linear take-make dispose economy (Lieder and Rashid, 2016). The European Union has set this in motion in their “Action plan for the Circular Economy” implementing a waste hierarchy in which prevention, reuse, recycling and energy recovery are favoured over landfill in this respective order (European Commission, 2015). Whilst this may help to reduce the input of waste in the long run, in the meantime the collection of marine litter is essential to reduce its stock and impact in the ocean.

Reviews of marine litter collections are frequently undertaken (Li, Tse and Fok, 2016; Keswani et al., 2016; Iñiguez, Conesa, and Fullana, 2016; Browne et al., 2015; Barnes and Miller 2004; Derraik, 2002) but there is no published quantitative overview describing the output of the various collection efforts (Law, 2017). Also, such reviews traditionally adopt an upstream perspective that focuses on input reduction and the impact of marine litter in the ocean rather than downstream activities for the collected litter (Figure 1; but see Iñiguez, Conesa, and Fullana, 2016). Yet, the investigation of collection and further downstream pathways is crucial to understand the full environmental impact of marine litter which is a necessary input to policy-making in this area.

This study reviews current literature relating to the collection of marine litter, and uses the findings to support a case for greater systems thinking and a fuller life cycle perspective towards collection and downstream treatment activities. This would enable both collection and treatment approaches to meet the Circular Economy and Sustainable Development Goals. It identifies where current gaps lie which currently prevent us from developing a full systems approach, and specifies what further data would be needed to progress this.

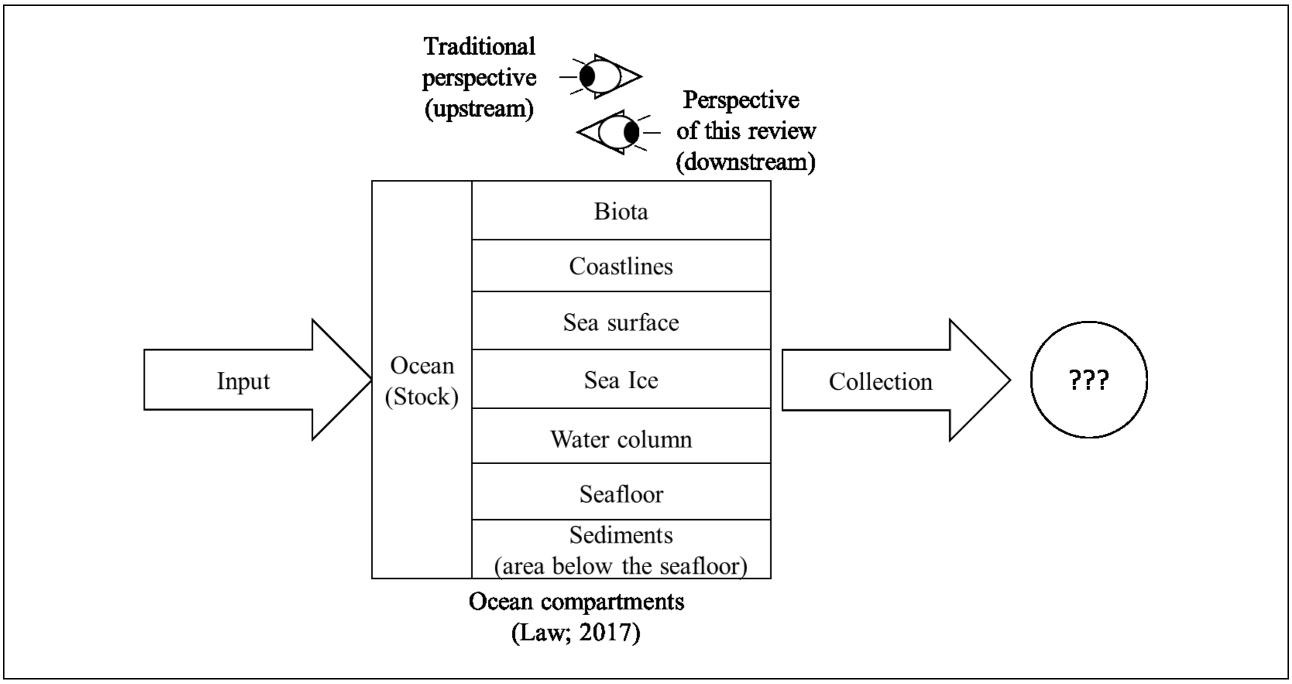

Figure 1: Marine litter flow and perspective of this review

2. Materials and methods

2.1 Literature search

Based on the mode of collection the literature has been divided into two groups: scientific and non-scientific collections. Scientific collections are studies that describe the typically very structured collection process in detail so that studies can be repeated and compared. For example, Alshawafi et al. (2017) marks several transects on a beach before starting the collection. Non-scientific collections on the other hand are result focused clean-up projects that do not commonly describe the collection process in detail.

Scientific collections

The literature search for scientific collections was based on peer-reviewed publications from the database Scopus using the title keywords "ocean", "sea" or "marine" in conjunction with "plastic" or "debris". After removing duplicates, 254 accessible articles published between January 2013 and April 2017 were evaluated in order to identify publications in which marine litter had been removed from the marine environment. Errata and reviews were excluded as were other publications when their methods section did not describe the marine litter collection protocol. This resulted in 103 publications.

Non-scientific collections

The search for non-scientific collections was based on references from the reviewed literature described above, the Global Ghost Gear Initiative (http://www.ghostgear.org/) and MARELITT (http://www.marelitt.eu/). The scientific publications and the Global Ghost Gear Initiative linked to individual removal projects worldwide whereas MARELITT had a focus on Europe specifically. In total 58 projects were identified for which a more detailed internet search was performed. For credibility, information was only taken from published documents and not from websites directly which gave 29 results.

2.2 Data extraction

From the 103 scientific and 29 non-scientific collection projects data about the (1) removal period, (2) location, (3) ocean compartment, (4) removed quantity, (5) collection method and (6) waste treatment was extracted. Subsequently, this data was sorted in a descending order based on the quantity collected (Appendix 1 and 2). When projects described multiple collections, data about the removed quantity and collection method were taken separately for each represented ocean compartment. This lead to 114 and 32 rows of data entries for the scientific and non-scientific collection projects respectively (Appendix 1 and 2).

2.3 Assumptions and limitations

Where a publication focused on derelict fishing gear and did not state otherwise it was assumed that the collection took place from the seafloor. Some publications give information in multiple formats, for example, by weight and by volume. To avoid double counting in these situations only one unit was extracted, giving priority in the order of: (1) weight, (2) item counts and (3) volume. For scientific collections from the coastline it was assumed that the collection was conducted manually if not otherwise specified.

This review is clearly limited to the approach and databases taken for the literature search. The approach focuses on marine litter collection but not on waste treatment pathways. Therefore such literature was excluded. The database Scopus has an emphasis on scientific studies but it has to be noted that the majority of marine litter is not reported in academic journals. Therefore other references, including the Global Ghost Gear Initiative and MARELITT were included, but this only provides a snapshot of the marine litter collections worldwide.

3. Results

3.1 Historic development

The starting date of the scientific and non-scientific collection projects indicate an increase of removal efforts over the last decade (Figure 2). This is possibly a response to the overall rise of awareness towards the problem following the long-term accumulation of plastic debris in the ocean (Petry and Benemann 2017). As studies are necessarily published retrospectively, the recorded decline between 2013 and 2016 may well be explained by the time needed to publish results for these recent time periods.

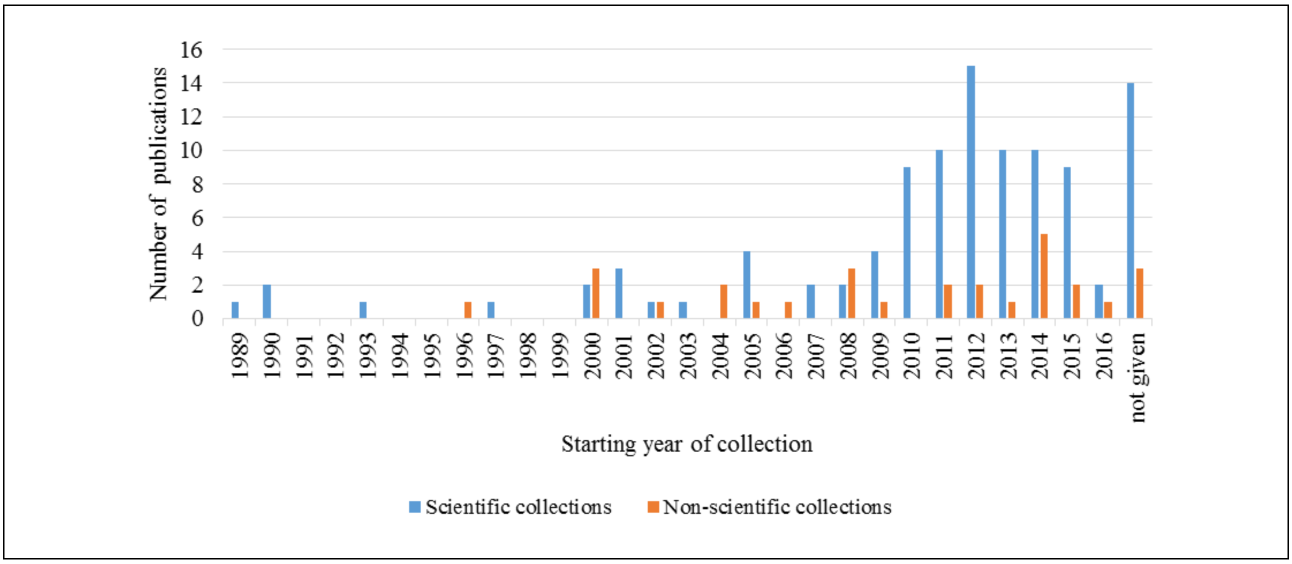

Figure 2: Development of marine litter collection efforts over time

Scientific collection projects are typically conducted over a limited and short period of time. Eight studies reported data collected from between four and eight years, and nine studies covered data from ten years or more. The remaining 71 studies for which data was available were conducted over a period of less than three years, of which the majority were single collection efforts that were started and completed within the same year.

Non-scientific collection projects are frequently designed for the long-term with no fixed end-date. Organisations typically publish the results of their collection efforts regularly, for example the International Coastal Cleanup on an annual basis (International Coastal Cleanup and Ocean Conservancy 2016). Yet, there are also clean-ups that are limited in time, for example after extreme weather events (Swanson et al., 2016) or when new collection approaches are tested (WWF Poland, 2015).

3.2 Geographical distribution

Figure 3 positions the reviewed marine litter collections in a world map based on Jambeck et al. (2015) so that the origin of plastic debris can be directly compared with the site of collection. Europe, North America and Australia undertake major collection efforts but also Brazil and South Korea are strongly represented.

Scientific collection projects tend to focus on the Mediterranean Sea, Brazil, the Pacific Ocean and Australia whereas non-scientific collection projects are typically conducted in the northern hemisphere. There is a notable gap between scientific and non-scientific efforts in South-America, Australia and Asia when South-Korea is excluded. This may suggest that there is further potential for scientific knowledge to trigger clean-up projects outside academia.

Russia, East and West Africa and the Western part of South America with the exception of Chile were not identified as locations of marine litter collections (Figure 3). Yet, scientific and non-scientific collection projects are undertaken worldwide and therefore additional investigation is needed to determine whether those areas have been studied before.

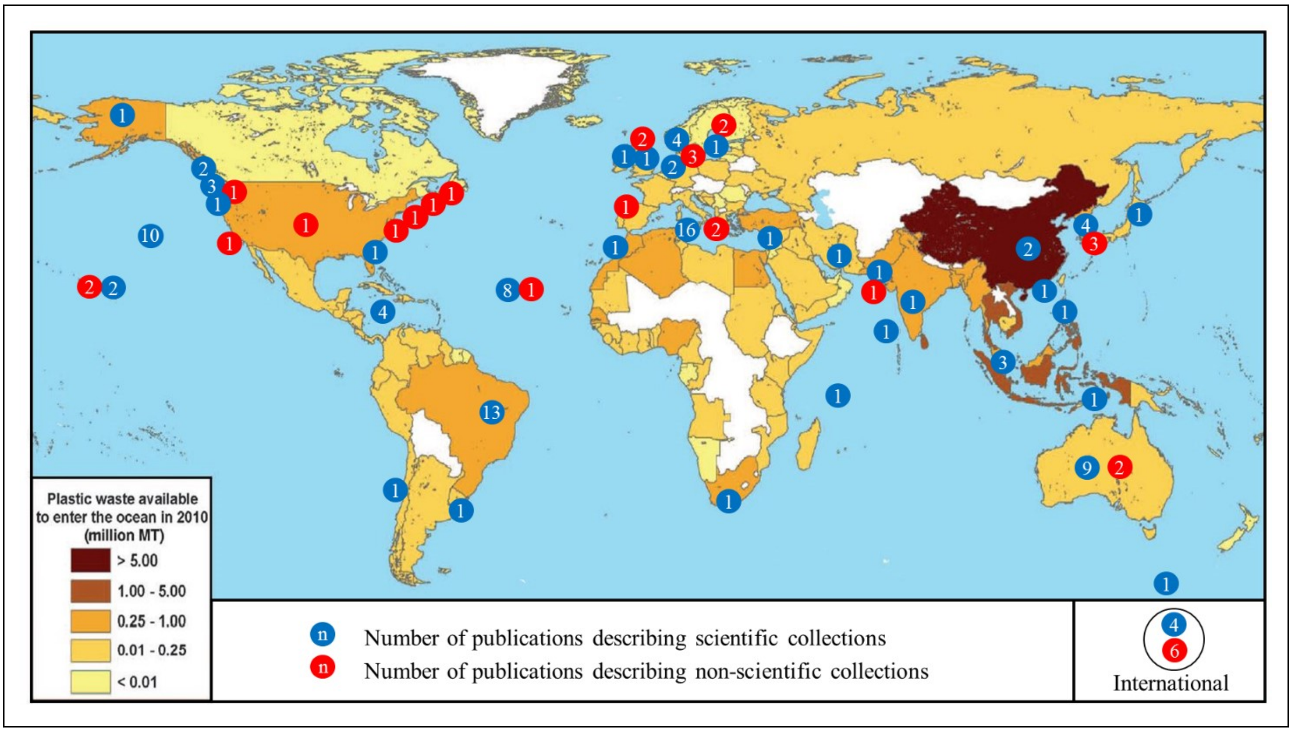

Figure 3: Geographical distribution of marine debris collections worldwide (map based on Jambeck et al., 2015), where collection locations were ascribed to regions or countries as whole

3.3 Systems perspective

A systems perspective looks at the interactions of single elements combining them to a whole picture which allows a better understanding of the context and implications of the system in its embedded environment. In this way the ocean compartments, quantities, collection methods and waste treatment pathways were joined (Figure 4).

Quantities and ocean compartments

Within the reviewed literature quantitative data was not provided for 42 of 146 collections and the 104 collections that provided quantitative data collected 259,822 tonnes, 1,121,734 items and 1,586 dm^3 of marine litter from the ocean (Figure 4).

Table 1: Number of scientific and non-scientific collections per ocean compartment

	Scientific collections		Non-scientific collections		Total collections	
	Number	Percentage	Number	Percentage	Number	Percentage
Coastlines	44	39%	10	31%	54	37%
Biota	32	28%	0	0%	32	22%
Sea surface	24	21%	3	9%	27	18%
Sea ice	0	0%	0	0%	0	0%
Seafloor	7	6%	19	59%	26	18%
Water column	1	1%	0	0%	1	1%
Sediments	6	5%	0	0%	6	4%
Total	114		32		146	

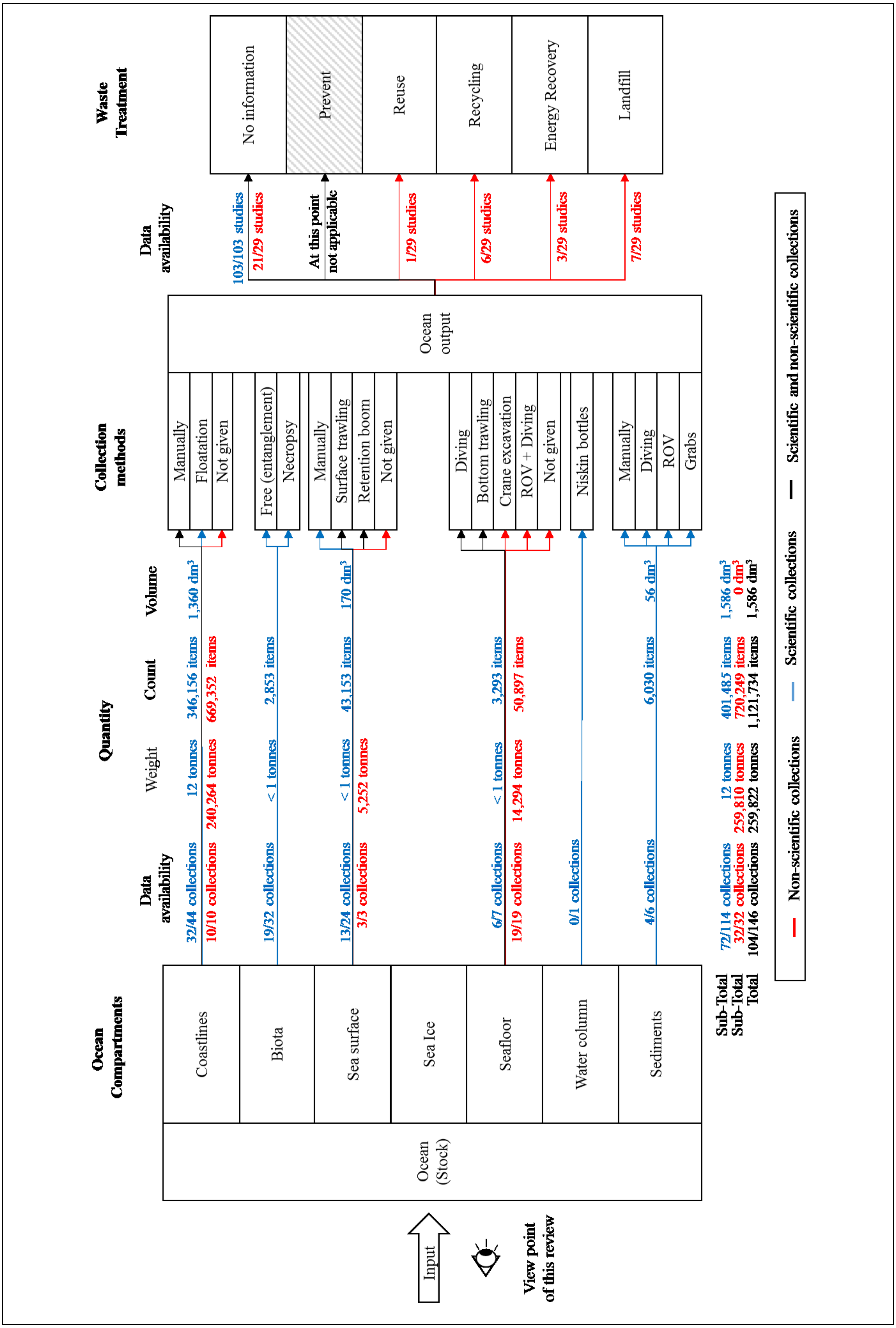

Figure 4: Flow of marine litter from the ocean to waste treatment

The 114 scientific collections that were described in the peer-reviewed publications covered all ocean compartments apart from the sea ice (Figure 4; Appendix 1). Quantitative data on the collected amounts were not available for 37% of the scientific collections including the one study collecting marine debris from the water column. For the remaining ocean compartments quantitative data was provided in 85.7%, 72.3%, 66.7%, 59.4% and 54.2% of the cases for the seafloor, sediments, coastlines, biota and the sea surface respectively. Most marine litter was collected from coastlines, which was also the most popular destination for removal activities (Table 1; Figure 4; Appendix 1).

The 32 non-scientific collections which were conducted outside academia removed marine litter from three out of seven ocean compartments; coastlines, sea surface and seafloor. Quantitative data was available for all collections. The largest amount of marine litter in terms of weight, item count and volume was picked up at coastlines followed by the seafloor and sea surface respectively. Non-scientific seafloor collections were undertaken almost twice as often as non-scientific coastline collections (Table 1, Figure 4; Appendix 2). This is unexpected given the large amount of regular beach clean-ups for example in local communities involving schools or local authorities. However, the relatively low number of non-scientific collections from coastlines can be explained by the review approach chosen in this study where non-scientific collections derived from websites such as the global ghost gear initiative that focuses on seafloor collections.

Collection methods

The collection methods used to remove marine litter from the ocean were typically described or implicitly given for scientific collections but only in 56.3% of the non-scientific collections (Figure 4; Appendix 1 and 2). Within the literature that contained information on collection methods, 16 ocean compartment specific ways of collection were identified (Figure 4; Appendix 1 and 2). The scientific collection methods typically focused on the removal of marine litter by hand or by smaller gear whereas non-scientific collections outside academia generally involved larger machines such as cranes.

The collection methods that were reported within both scientific and non-scientific collections were: (1) manual removal of marine litter from the coastline, (2) surface trawling and (3) use of a retention boom to capture floating marine litter at the sea surface as well as (4) bottom trawling and (5) diving to pick up marine litter from the seafloor (Figure 4; Appendix 1 and 2). For manual collections from the coastline typically gloves and plastic bags are used to protect hands and store the marine litter. A retention boom is a floating barrier that collects buoyant litter passively by making use of water currents. During surface and bottom trawling nets are towed behind a ship although with different mesh size so that mainly smaller items are collected from the sea surface and larger items from the seafloor possibly as by-catch from normal fishing activities. Also diving is used to collect litter from the seafloor although it is restricted to shallow waters.

Scientific collection methods include: (1) flotation, (2) freeing, (3) necropsy, (4) Niskin bottles, (5) manual collection of marine litter from the sea surface and (6) sediment (Figure 4; Appendix 1). Also, (7) diving, (8) remotely operated vehicles (ROVs) and (9) grabs were used (Figure 4; Appendix 1). Flotation separates buoyant, typically microplastics from beach sediment using sea water and sieves. Freeing describes the attempt to remove marine litter from entangled animals typically to save their life. Necropsy is the removal and content analysis of a dead animals' intestine tract which is frequently conducted to study the impact of plastic debris ingestion on marine life. Niskin bottles are used to take samples from the water column. At the sea surface manual collections were conducted from ships whereas sediment samples were taken by divers or from shallow waters directly. In greater depth grabs and ROVs can be used to collect sediments.

Within the non-scientific collections marine litter was removed from the seabed using a (1) crane excavation and by employing a (2) combination of ROVs and divers (Figure 4; Appendix 2). The crane operates from a ship which makes it mobile in the ocean. The benefit of using ROVs and divers together is that ROVs can detect marine litter and divers can assist retrieving them if needed.

Waste treatment

For the waste treatment of the collected marine litter almost no information is available. In fact, only 27.6% of the publications describing non-scientific collections mentioned the waste treatment of marine litter whereas it was not mentioned in scientific collections at all. This is noteworthy, especially for larger removal activities that collected up to ten tonnes and more (Polasek, Bering et al., 2017) because the question about their final treatment remains unanswered.

The non-scientific collections that described the waste treatment of collected marine litter cover all available treatment options: reuse, recycle, energy recovery and landfill. Prevention of marine litter implies a reduction of waste input into the ocean. As the input of waste happens much earlier in the life cycle of marine litter compared to its treatment after collection, prevention is not applicable at this point (Figure 4).

In one study, derelict fishing gear was collected from the ocean, cleaned and subsequently reused for its former function (FUNDY NORTH Fisherman's Association, 2016). Recycling was also possible for other materials for example metals (National Fish and Wildlife Foundation, 2016) such as lead line (Northwest Straits Foundation, 2015) or polystyrene buoys (Iñiguez, Conesa, and Fullana, 2016). Yet, material recycling is challenging because collected marine litter is usually contaminated and requires several pre-treatment steps including the separation of sand from plastics and cleaning (Iñiguez, Conesa, and Fullana, 2016). Commonly encountered small fluctuating quantities of collected marine litter (Fishing for litter Scotland, 2015; 2017) as well as a low oil price pose further challenges to recycling because such conditions do not favour investments which are needed to set up a recycling plant. Apart from material recycling, marine litter was also turned into art (Ghost nets Australia, n.d.; Olive Ridley Project, 2017). Energy recovery from marine litter was possible in some cases (Swanson et al., 2016; Iñiguez, Conesa, and Fullana, 2016; National Fish and Wildlife Foundation, 2016) but not in others due to its elevated heating (Fishing for litter Scotland, 2015; 2017). Due to those complications some parts, if not all (Fishing for litter Scotland, 2015; 2017), of the collected litter was disposed in landfills (Figure 4; Appendix 2).

4. Discussion

Marine litter collections are not new but there has been a notable rise in reported activity within the last ten years, with rising awareness and visibility of the plastic debris problem. Although collection efforts may increase, it does not necessarily reduce the overall stock of marine litter in the ocean because a growing and much larger amount of new waste, in particular plastics, is added to the marine environment every year (Jambeck et al., 2015). It needs both a drastic input reduction and increase of collection efforts to achieve the Sustainable Development Goal 14.1 which requires an input prevention and a significant stock decline by 2025 (United Nations General Assembly, 2015). For performance measurements and estimates on when the accumulation of marine litter might begin to decline, data on the current stock, annual in- and output are needed. This review is a first step in collating such output data on a global scale but further investigation is obviously required.

The collection of marine litter is undertaken worldwide but it may be expected that regions suffering from marine litter are conducting more clean-up activities than other regions. Yet, from the top ten contributors of marine plastic debris: China, Indonesia, Philippines, Vietnam, Sri Lanka, Thailand, Egypt, Malaysia, Nigeria and Bangladesh (Jambeck et al., 2015) only Malaysia, China and the Philippines lead collection projects within the reviewed literature. A possible explanation for this is that contributing countries are not necessarily the countries who suffer from the pollution, although this seems very unlikely because waste does not just disappear after its disposal. It appears more plausible to link collection efforts to the wealth of a country because resources, a functional waste management infrastructure, education and awareness are needed to provide the basis for clean-up activities. It is also possible that collections exist but were not reported.

In current literature collected marine litter is quantified by weight, item counts or volume when values are given at all. This makes a direct comparison difficult. It would be beneficial to express the collected quantities as a single unit, especially for the large amounts that become relevant from a waste treatment perspective. Nevertheless, the results show that coastline collections yield by far the largest amounts, followed by the seafloor and subsequently the remaining ocean compartments. The inclusion of additional data from local authorities would be expected to support this observation, as coastlines are routinely cleaned. This also suggests, that the amount of collected marine litter analysed in this study is a low estimate. On the other hand it can be argued that the data from non-scientific collections may be overestimated and inaccurate: They may also include stones, sand and water which do not fall under the definition of marine litter but have a relatively high weight compared to plastic debris. The distinction of marine litter is especially difficult for coastline collections where it is not clear whether the litter originated from the ocean or from land. Thus, the numbers should be taken with all due care.

Within the reviewed literature much of the marine litter was collected manually. This indicates ample room for process development to automate current collection methods and make them more efficient. Yet, an automation implies the use of machines that entail environmental impacts from upstream activities such as energy generation. Environmental impacts can also be more direct for example to the seafloor from dragging operations (Erftemeijer et al., 2012) and it needs careful consideration as to whether a collection realises more benefits than it does harm. In general collections that can be conducted as part of the normal human presence in the marine environment for example beach clean-ups or the removal of marine litter by-catch from fishing nets appear the most cost effective and environmentally friendly solutions.

Information on the material composition of the collected marine litter is important for waste treatment companies because it determines the required pre-treatment steps for each waste treatment approach. A limitation of this study is that representative information on the weight-based material composition could not be compiled, because the data was only available for few large-scale collections. In those, litter from the coastlines comprised of 60% plastic, 15% rope and netting, 13% foam, 10% other including rubber and 2% metal (Polasek et al., 2017) whereas litter from the seafloor contained 52% to 76% plastics including derelict fishing gear, 5% to 11% metal, 4% to 14% rubber, 3% to 18% timber, 2% to 5% textiles and up to 20% other (Fishing for litter Scotland, 2015; Lueiro, 2013; Naturschutzbund Deutschland, 2015). Despite large uncertainties this confirms that collected marine litter is a very diverse mix of materials that is especially difficult to separate, clean and recycle. However, as incineration and landfilling is not encouraged within the Circular Economy, information on alternative waste treatment options for marine litter is needed.

In understanding challenges related to marine litter management it is vital that a systems perspective is sought. Apart from ocean compartments, quantities, collection methods and waste treatment options which have been linked in this study other elements of the supply chain such as transportation and the harbour reception need to be included in this system. Thus, a quantitative environmental assessment of the system is needed to confirm that the best possible collection methods and subsequent treatment options are used. It also ensures that both the direct collection and processing route is optimised to be most environmentally beneficial, and that any indirect consequences arising from the utilisation of marine litter are also included. In order to do this, further data about material flows and process data are needed.

5. Conclusions

Continuous waste input to the ocean and its accumulation in the marine environment has severe impacts on marine life, humans and the economy. This includes accidents and harm caused by entanglement and ingestion, the spread of invasive species across the ocean, the extinction of corals and a decline in tourism. While research is still conducted to understand the full extent of its impacts, the literature also shows that initiatives have already started to respond to the problem.

The immediate short-term solution that was analysed in this study was the collection of marine litter from the ocean. In 103 scientific studies and 29 projects from outside academia more than 250 thousand tonnes, 1 million items and 1.5 m^3 of marine litter have been removed from all ocean compartments apart from the sea ice using at least 16 different collection methods. From those the manual removal of marine litter from the coastline contributed most to the overall collection. However, with all this effort and an increasing number of ongoing projects it is not possible so far to counteract the yearly input of plastic waste to the ocean. This implies that the amount of marine litter is still increasing despite ongoing collection effort. In order to meet the Sustainable Development Goals much more marine litter must be collected and it should be further investigated which collection method is the most suitable to do so.

Increased collection efforts also spark the interest in the waste treatment of collected marine litter. Yet, none of the 103 scientific studies mentioned such pathways after collection. However, within the non-scientific projects landfilling and energy recovery were described as common pathways but also recycling and reuse was possible for some parts of the collected litter. In light of the Circular Economy and its waste hierarchy further investigation on waste treatment options for marine litter is necessary to minimise current and future environmental impacts.

A full system quantitative assessment from the impact of litter collections on the marine environment all the way to reuse and recycling options is needed to help policy makers and waste treatment companies identify the collection and treatment pathways of marine litter that are most environmentally friendly and minimise undesired side effects. This requires data and further study of material flows as well as process data.

Acknowledgements

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Appendix 1 – Extracted data from scientific collections

Nr	Removed quantity		Ocean compartment	Collection method	Location	Removal period	Waste treatment	Collector / Reference
	Value	Unit						
1	10404	kg	Coastline	Manually	Alaska (USA)	2015	-	(Polasek et al., 2017)
2	422	kg	Seafloor	Bottom trawling	Pacific Ocean	2003-2011	-	(Goto and Shibata, 2015)
3	244	kg	Coastline	Manually	Caribbean Sea	2015	-	(De Scisciolo et al., 2016)
4	231	kg	Coastline	Manually	Malaysia	-	-	(Mobilik et al., 2015)
5	227	kg	Seafloor	Bottom trawling	Mediterranean Sea	2010-2012	-	(Eryasar et al., 2014)
6	181	kg	Coastline	Manually	Brazil	2011-2012	-	(Da Silva et al., 2015a)
7	167	kg	Coastline	Manually	Malaysia	2014	-	(Yi and Kannan, 2016)
8	142	kg	Coastline	Manually	Seychelles	2013	-	(Duhec et al., 2015)
9	130	kg	Coastline	Manually	India	2015	-	(Arun Kumar et al., 2016)
10	74	kg	Coastline	Manually	Belgium	2010-2011	-	(Van Cauwenberghe et al., 2013)
	<1	kg	Sea surface	Surface trawling				
	<1	kg	Seafloor	Bottom trawling				
11	39	kg	Biota	Necropsy	North Sea	2016	-	(Unger et al., 2016)
12	30	kg	Sea surface	Retention boom	Hawaii (USA)	2011-2012	-	(Carson et al., 2013)
13	30	kg	Coastline	Manually	Brazil	2013	-	(Da Silva et al., 2016)
14	19	kg	Coastline	Manually	Malaysia	-	-	(Kadir, Hasni and Sarani, 2015)
15	16	kg	Coastline	Manually	Brazil	-	-	(Leite et al., 2014)
16	13	kg	Coastline	Manually	Morocco	2015	-	(Alshawafi et al., 2017)
17	12	kg	Coastline	Manually	Pakistan	2012	-	(Qari, 2015)
18	12	kg	Coastline	Manually	South Korea	2013	-	(Jang et al., 2014a)
19	4	kg	Coastline	Manually	Caribbean Sea	2011	-	(Debrot et al., 2013)
20	1	kg	Coastline	Manually	United Kingdom	2015	-	(Turner, 2016)
21	<1	kg	Biota	Necropsy	Brazil	2009-2013	-	(Santos et al., 2015)
22	<1	kg	Biota	Necropsy	Pacific Ocean	1993-2011	-	(Wedemeyer-Strombel et al., 2015)
23	<1	kg	Biota	Necropsy	Brazil	2009-2010	-	(Poli et al., 2015)
24	<1	kg	Biota	Necropsy	Mediterranean Sea	2005-2015	-	(Casale et al., 2016)
25	<1	kg	Biota	Necropsy	Mediterranean Sea	2010-2011	-	(Campani et al., 2013)
26	<1	kg	Biota	Necropsy	Pacific Ocean	2010-2011	-	(Jantz et al., 2013)
27	<1	kg	Sea surface	Surface trawling	Atlantic Ocean	2015	-	(Kooi et al., 2016)
28	<1	kg	Sea surface	Surface trawling	Atlantic Ocean	2014	-	(Ter Halle et al., 2016)
29	<1	kg	Biota	Necropsy	Washington (USA), British Columbia (Canada)	2001-2011	-	(Avery-Gomm et al., 2013)
30	<1	kg	Biota	Necropsy	Atlantic Ocean	2011-2012	-	(Bond et al., 2013)

31	179904	items	Coastline	Flotation	Hong Kong	2014-2015	-	(Cheung, Cheung and Fok, 2016)
32	69122	items	Coastline	Manually	Israel	2012-2015	-	(Pasternak et al., 2017)
33	46728	items	Coastline	Manually	Mediterra-nean Sea	2011-2013	-	(Smith and Markic, 2013)
34	32414	items	Sea sur-face	Surface trawling	Pacific Ocean	2009-2010	-	(Goldstein, Titmus and Ford, 2013)
35	17089	items	Coastline	Manually	Brazil	2012-2013	-	(Fernandinoet al., 2016)
36	8055	items	Coastline	Manually	Chile	2002-2005	-	(Thiel et al., 2013)
37	6527	items	Coastline	Manually	Georgia (USA)	2012-2013	-	(Martin, 2013)
38	6389	items	Coastline	Manually	Sub-Antarc-tic island	2000-2001	-	(Eriksson et al., 2013)
39	6030	items	Sediments	Diving	Mediterra-nean Sea	2015	-	(Blaskovic et al., 2017)
40	4618	items	Coastline	Manually	Australia	2011-2013	-	(Hardesty et al., 2017)
41	4520	items	Coastline	Manually	Australia	2012	-	(Smith, Gillies, and Short-land-Jones, 2014)
42	3901	items	Sea sur-face	Surface trawling	Mediterra-nean Sea	2013	-	(Cozar et al., 2015)
43	3070	items	Sea sur-face	Surface trawling	International	2010-2011	-	(Cozar et al., 2014)
44	2986	items	Seafloor	Diving	Australia	2005-	-	(Smith and Edgar, 2014)
45	2673	items	Sea sur-face	Surface trawling	Mediterra-nean Sea	2012-2013	-	(De Lucia et al., 2014)
46	1992	items	Coastline	Manually	Brazil	-	-	(Santos et al., 2016)
	656	items	Biota	Necropsy				
47	1315	items	Biota	Necropsy	Indian Ocean	2007-2013	-	(Hoarau et al., 2014)
48	839	Items	Sea sur-face	Surface trawling	Australia	2011-2012	-	(Reisser et al., 2013)
49	587	items	Coastline	Flotation	China	2014	-	(Zhao, Zhu, and Li, 2015)
50	553	items	Biota	Necropsy	Brazil	1990-2014	-	(Petry and Benemann, 2017)
51	493	items	Coastline	Manually	Brazil	2016	-	(Tavares et al., 2016)
52	291	items	Seafloor	Bottom trawling	Atlantic Ocean	-	-	(Possatto et al., 2015)
53	162	items	Sea sur-face	Surface trawling	Pacific Ocean	2000-2001	-	(Uchida et al., 2016)
54	138	items	Biota	Free (entan-glement)	Australia	1997-2012	-	(Lawson et al., 2015)
55	84	items	Coastline	Manually	Ashmore Reef	2013	-	(Lavers, Hodgson and Clarke, 2013)
56	68	items	Sea sur-face	Surface trawling	Australia	-	-	(Reisser et al., 2014)
57	50	items	Biota	Necropsy	Pacific Ocean	-	-	(Gilbert et al., 2015)
58	26	items	Sea sur-face	Manually	Mediterra-nean Sea	2009	-	(Masó et al., 2016)
	16	items	Seafloor	Bottom trawling				
59	39	items	Biota	Necropsy	Uruguay	2005-2013	-	(Jimenez et al., 2015)

60	37	items	Biota	Necropsy	Mediterranean Sea	2010	-	(Anastasopoulou et al., 2013)
61	29	items	Biota	Necropsy	Mediterranean Sea	2012-2013	-	(Romeo et al., 2015)
62	29	items	Coastline	Manually	South Korea	2014	-	(Rani et al., 2017)
63	19	items	Biota	Necropsy	Atlantic Ocean	-	-	(Di Beneditto and Ramos, 2014)
64	19	items	Coastline	Manually	South Korea	2014	-	(Rani et al., 2015)
65	17	items	Biota	Necropsy	Philippines	2015	-	(Abreo et al., 2016)
66	1360	dm^3	Coastline	Manually	Caribbean Sea	2014	-	(Bennett-Martin, Visaggi, and Hawthorne, 2015)
67	-	-	Coastline	Manually	International	-	-	(Kwon et al., 2015)
	170	dm^3	Sea surface	Manually				
68	56	dm^3	Sediments	Manually	Mediterranean Sea	2015-2016	-	(Guerranti et al., 2017)
69	-	-	Sea surface	Surface trawling	Caribbean Sea	2013-2014	-	(Correa-Herrera et al., 2017)
70	-	-	Biota	Necropsy	Brazil	2010-2013	-	(Jerdy et al., 2017)
71	-	-	Coastline	Manually	Australia	2012	-	(Wilson and Verlis, 2017)
72	-	-	Coastline	Manually	Iran	2005	-	(Sarafraz, Rajabizadeh and Kamrani, 2016)
73	-	-	Biota	Necropsy	Ireland	2012-2016	-	(Acampora et al., 2016)
74	-	-	Biota	Necropsy	Mediterranean Sea	2012	-	(Battaglia et al., 2015)
75	-	-	Sediment	Diving	Mediterranean Sea	-	-	(Fastelli et al., 2016)
76	-	-	Biota	Necropsy	Japan	2012-2015	-	(Fukuoka et al., 2016)
77	-	-	Sea surface	Surface trawling	Atlantic Ocean	2014	-	(Gigault et al., 2016)
78	-	-	Sea surface	Manually	Pacific Ocean	2012	-	(Gil and Pfaller, 2016)
79	-	-	Sea surface	Surface trawling	Mediterranean Sea	2013	-	(Pedrotti et al., 2016)
80	-	-	Sea surface	Surface trawling	Mediterranean Sea	2011-2013	-	(Ruiz-Orejon, Sarda, and Ramis-Pujol, 2016)
81	-	-	Biota	Necropsy	North Sea, Baltic Sea	2013	-	(Rummel et al., 2016)
82	-	-	Biota	Necropsy	South Africa	1989 - 2014	-	(Ryan, de Bruyn, and Bester, 2016)
83	-	-	Sediment	ROV	Pacific Ocean	2011 - 2013	-	(Taylor et al., 2016)
84	-	-	Coastline	Manually	Washington (USA), Oregon (USA)	2012-2016	-	(West et al., 2016)
85	-	-	Coastline	Manually	China	2007-2013	-	(Zhou et al., 2016)
	-	-	Sea surface	Surface trawling				
86	-	-	Coastline	Manually	Hawaii (USA)	1990-2012	-	(Agustin et al., 2015)
87	-	-	Biota	Necropsy	Brazil	2008-2009	-	(Da Silva et al., 2015b)
88	-	-	Coastline	Manually	Washington (USA), British Columbia (Canada)	2008 - 2012	-	(Davis and Murphy, 2015)
	-	-	Sea surface	Surface trawling				

89	-	-	Biota	Necropsy	Brazil	2011	-	(De Carvalho et al., 2015)
90	-	-	Coastline	Manually	North Sea	2014	-	(De Tender et al., 2015)
			Water column	Niskin bottles				
			Seafloor	Bottom trawling				
			Sediment	Grabs				
91	-	-	Sea surface	Surface trawling	Atlantic Ocean	2014	-	(Reisser et al., 2015)
92	-	-	Coastline	Manually	Belgium	-	-	(Gauquie et al., 2015)
93	-	-	Coastline	Manually	South Korea	2013-2014	-	(Lee et al., 2015)
94	-	-	Coastline	Manually	Australia	2012-2013	-	(Verlis, Campbell and Wilson, 2014)
95	-	-	Biota	Necropsy	Brazil	-	-	(Di Beneditto and Awabdi, 2014)
96	-	-	Sea surface	Surface trawling	International		-	(Eriksen et al., 2014)
97	-	-	Sea surface	Surface trawling	Pacific Ocean	2001-2012	-	(Law et al., 2014)
98	-	-	Sea surface	Surface trawling	Atlantic Ocean	2010	-	(Rochman et al., 2014)
	-	-	Biota	Necropsy				
99	-	-	Sediment	ROV	International	2001-2012	-	(Woodall et al., 2014)
100	-	-	coastline	Manually	Mediterranean Sea	2013-2014	-	(Kalogerakis and Fava, 2014)
101	-	-	Biota	Necropsy	North Sea	2010-2011	-	(Foekema et al., 2013)
102	-	-	Biota	Necropsy	Pacific Ocean		-	(Tanaka et al., 2013)
103	-	-	Biota	Necropsy	Australia	2012	-	(Verlis, Campbell and Wilson, 2013)

Appendix 2 – Extracted data from non-scientific collections

Nr	Removed quantity		Ocean compartment	Collection method	Location	Removal period	Waste treatment	Collector / Reference
	Value	Unit						
1	176940	tonnes	Coastline	-	New York (USA)	2012	Energy recovery, landfill	Local authorities (Swanson et al. 2016)
2	27297	tonnes	Coastline	-	South Korea	annually	-	Local authorities (Jang et al. 2014b)
	3946	tonnes	Sea surface	-				
	11370	tonnes	Seafloor	-				
3	10285	tonnes	Coastline	-	South Korea	2000-2006	-	Korean Coastal cleanup campaigns (NOAA Marine Debris Program 2015)
4	8193	tonnes	Coastline	Manually	International	2015	-	International Coastal Cleanup and Ocean Conservancy (2016)
5	7342	tonnes	Coastline	Manually	International	2014	-	International Coastal Cleanup and Ocean Conservancy (2015)
6	5592	tonnes	Coastline	Manually	International	2013	-	International Coastal Cleanup and Ocean Conservancy (2014)
7	4603	tonnes	Coastline	Manually	International	2012	-	International Coastal Cleanup and Ocean Conservancy (2013)
8	1300	tonnes	Sea surface	Retention boom	South Korea	annually	Recycling, energy recovery, landfill	Local authorities (Iñiguez, Conesa, and Fullana 2016)
	350	tonnes	Seafloor	Crane excavation				
9	908	tonnes	Seafloor	Bottom trawling	Atlantic Ocean, North Sea	2005-2015	Landfill	Fishing for litter Scotland (2015, 2017)
10	820	tonnes	Seafloor	-	Hawaii (USA)	1996-2014	-	Pacific Islands Fisheries Science Center (NOAA Marine Debris Program 2015)
11	268	tonnes	Seafloor	Bottom trawling	Baltic Sea	2015	-	WWF Poland (2015)
12	250	tonnes	Seafloor	-	USA	2008	Recycling of metal, energy recovery, landfill	National Fish and Wildlife Foundation (2016)
13	104	tonnes	Seafloor	Diving	International	2014-2015	-	Project AWARE (International Coastal Cleanup and Ocean Conservancy, 2015; 2016)
14	67	tonnes	Seafloor	Bottom trawling	United Kingdom	2014-2015	-	Fishing for litter South West (2015)
15	60+	tonnes	Seafloor	-	California (USA)	2006-2012	-	CA lost fishing gear recovery project (NOAA Marine Debris Program 2015)

16	37+	tonnes	Seafloor	ROV + Diving	Washington (USA)	2002-2016	Recycling of lead line, landfill	Northwest Straits Foundation (2015)
17	34	tonnes	Seafloor	Bottom trawling	Spain	2009-2010	-	CETMAR (Lueiro, 2013)
18	20	tonnes	Seafloor	-	North Sea, Mediterranean Sea	2000-2006	-	Healthy Seas Initiative (NOAA Marine Debris Program 2015)
19	12	tonnes	Coastline	-	Hawaii (USA)	2014	-	US marine park Papahānaumokuākea (Cressey, 2016)
20	6+	tonnes	Sea surface	Surface trawling	Australia	2004-2014	Recycling into art, landfill	Ghost nets Australia (n.d.)
21	2+	tonnes	Seafloor	Bottom trawling	North Sea, Baltic Sea	2011-2014	-	Naturschutzbund Deutschland (2015)
22	2+	tonnes	Seafloor	Bottom trawling	New Brunswick (Canada)	2008-2015	Reuse fishing gear, recycling of rope, landfill	FUNDY NORTH Fisherman's Association (2016)
23	1	tonnes	Seafloor	-	Pakistan, Maledives	<2016	Recycling into art	Olive Ridley Project (2017)
24	1	tonnes	Seafloor	Diving	Mediterranean Sea	2014-2016	-	Italian Institute of Marine Sciences (2016)
25	400,968	items	Coastline	Manually	International	2011-2014	-	Marine debris tracker (Jambeck and Johnsen2015)
26	268384	items	Coastline	Manually	United Kingdom	2016	-	Marine Conservation Society (2016)
27	33297	items	Seafloor	-	Virginia (USA)	2008-2013	-	CCRM VIMS (NOAA Marine Debris Program 2015)
28	12,000+	items	Seafloor	-	Australia	2004-2012	-	GhostNets Australia (NOAA Marine Debris Program 2015)
29	5,600	items	Seafloor	-	Maine (USA)	2000-2006	-	Gear Grab.org (NOAA Marine Debris Program 2015)